APPENDIX F: TECHNICAL DESCRIPTION OF DATA, RISK–ADJUSTMENT METHODS AND RESULTS

Since patients differ in the severity of their clinical condition, it is unfair to compare two hospitals based on their results in treating patients without taking these differences into account. CCMRP "levels the playing field" by accounting for the pre–operative condition of a patient at the time he or she is admitted to the hospital. This leveling is called "risk–adjustment." Hospitals that routinely handle tougher cases receive larger risk–adjustment factors, while hospitals that handle easier cases receive smaller ones. In adjusting for patients' risks, only those factors are included that describe the patient's condition as closely as possible to the time of hospital admission. The goal is to produce a statistical model that can be used to risk–adjust hospital outcomes by *removing* patient factors that exist prior to the hospitalization that can have an effect on survivorship. After accounting for these factors, what is left is presumed to be a combination of differences in the effectiveness of the care provided, plus some random error due to chance.

The modeling of CABG mortality can be approached in a number of ways, some of which are mentioned in our reference section. However, multivariate logistic regression models have become the standard method of analyzing binary data in health services research, and this is the method CCMRP selected. This section of the report describes in detail the methods used to create a risk–adjustment model and to calculate risk–adjustment factors for each hospital. Also discussed are some of the alternative models investigated and the detailed results. This technical appendix is organized into five main sections:

- ***Data***, which includes a discussion of how CCMRP selected the data elements (i.e., patient characteristics), data cleaning and manipulation procedures, and the process used to validate the quality of those data.
- ***Model Development***, which relates the patient characteristics to in–hospital mortality following isolated CABG surgery, and includes a discussion of how missing data elements were handled; and the choice of analytic technique.
- ***Model Fit and Validation***, which discusses the discrimination and calibration of the logistic regressive model.
- ***Alternative Models***, which includes a discussion of alternative analytic approaches.
- ***Hospital Risk–Adjusted Mortality Predictions***, in which we remove the effect of the patient characteristics on the outcome; what is left is an estimate of the effect of the hospital on the outcome.

Data

The risk analysis is based on 30,800 isolated CABG cases that CCMRP collected from 82 California hospitals that submitted data to CCMRP for 1997 and 1998. Although this is CCMRP's first public report, the number of cases and participating hospitals already makes CCMRP the largest public reporting program on coronary bypass surgery. Unlike CABG outcome reports produced by several other states in which participation is mandatory, CCMRP is voluntary and

hospitals choose to participate. For the 1997–1998 period, 79 hospitals out of 118 California hospitals that perform significant numbers of adult CABG surgeries chose to share their data for analysis and public reporting. Together these participating hospitals perform more than 70% of all CABG surgeries in California. Although the vast majority of hospitals joined CCMRP, we caution that the results and conclusions in this report are applicable only to those hospitals that submitted data and not to hospitals that refused to participate.

Because CCMRP continued to recruit throughout 1997 and 1998, the amount of data for each participating hospital may vary not only by the size of the hospital but also by when they chose to join. All hospitals in this analysis submitted data for 1998, but some also submitted data for all or part of 1997. In aggregate, about 38% of the total cases were from 1997 (11,808) and 62% were from 1998 (19,006). As an indication of continuing participation by hospitals, as of November 1, 2000, preliminary counts indicate that approximately 22,000 additional cases have been submitted for the year 1999.

CCMRP collected a small number of data elements for each adult patient who underwent an isolated CABG surgery (*isolated* means that no patient in this analysis received both a CABG and an additional major procedure such as a valve repair or replacement during the same operation) between January 1, 1997, and December 31, 1998. As discussed elsewhere in this document, our review of the clinical literature suggested that only a very small set of pre–operative data elements were necessary to risk–adjust isolated CABG surgery outcomes. The data elements (see Appendix A) focus on demographic characteristics and the pre–operative condition or risk factors of the patient, and they include all pre–operative data elements suggested by an expert panel for inclusion in any analysis of isolated CABG surgeries (see Jones et al., 1996). This expert panel identified seven "core" pre–operative variables that were unequivocally related to mortality, 13 "Level 1" variables that are likely to have a relationship, and 24 "Level 2" variables not clearly shown to relate directly to short–term CABG mortality, but which hold potential research or administrative interest. CCMRP collected all "core" and "Level 1" data elements, and almost all "Level 2" data elements.

A total of 802 patients (out of 30,814) died in–hospital following the procedure for an overall in–hospital death rate of 2.60%. To put this in context, in their January 2001 report on the outcomes for CABG surgery for 1998, the New York State Department of Health reported 405 deaths out of 18,814 isolated CABG cases for an overall in–hospital mortality rate of 2.15% (see www.health.state.ny.us). And, although not strictly comparable, the California Chapter of the STS reports an overall operative mortality rate for its California members of 3.03% for the three–year period from October 1, 1994, to September 30, 1997 (see www.casts.org). "Operative mortality" differs from "in–hospital mortality" used by CCMRP in that it measures mortality within 30 days of a CABG surgery (unless the cause of death is clearly not related to the operation). Because most (but not all) deaths after CABG occur within 30 days, operative mortality is generally higher than in–hospital mortality.

Data Collection. The data elements collected by CCMRP and used in the risk–adjustment model are a subset of the data elements collected by the STS for their National Database of Cardiac Surgery. Although the definitions used for each of these data elements were quite similar, to improve the quality and comparability of data submitted by hospitals, CCMRP required that hospitals send staff who would have responsibility for collecting these data to a training

session prior to being allowed to submit data. The training sessions were lead by a cardiologist. A training session included a short presentation of the goals of the project, a detailed discussion of variable definitions and coding practices, review of a series of training vignettes, and a quiz to test participant's knowledge and ability to code correctly given the definitions. After training, CCMRP collected data quarterly from participating hospitals. A copy of the training manual is available on the web from OSHPD (www.oshpd.state.ca.us/hpp), as well as videotape of a training session.

Data collection is continuing for current years. As a note for future interest, data elements and definitions for the year 1999 are exactly as those used for these data (1997–1998); however, a few changes have been made to CCMRP data elements for the year 2000 in accordance with updated definitions by the STS for their own national cardiac surgery database.

Data Cleaning and Transformation. Although each hospital was required to attend a training session prior to data submission, a great deal of variability occurred in the apparent distribution of data, necessitating substantial pre–analysis data cleaning. Upon receipt of the quarterly data, CCMRP staff conducted a series of short summary checks to ensure that no obvious errors had occurred (such as the omission of age or patient status). When they detected such errors, CCMRP staff contacted the hospital and requested either clarification or re–submission. Subsequent to this stage, staff performed minor data transformations (e.g., recoding of "Yes" to "Y" and "No" to "N," collapsing of race/ethnicity categories to "White" and "Non–white," and calculating ages from dates of birth and surgery).

The preliminary data cleaning found that the value of creatinine was missing or recorded as "0" in approximately one–third of all cases submitted for analysis. In 1997 and 1998 (and also for the year 1999), the STS did not collect creatinine values unless those values exceeded 2.0. As a result, this coding practice among hospitals participating in the STS system makes it impossible to distinguish in the CCMRP data set between creatinine values below 2.0 (i.e., missing by design) and those that are truly missing (whether the value is below or above 2.0). This was true of other data elements collected by CCMRP. The next section discusses the consequences, alternatives that CCMRP explored to address this problem, and the policy recommendation adopted to handle missing data. After considering the alternatives in the next section, CCMRP assumed that all missing values of creatinine were "normal," and assigned them the value 1.0 mg/dl.

The STS data system collects "Yes/No" values for several data elements, including some patient history elements that describe co–morbidities (e.g., presence or absence of diabetes) and conditions or procedures that apply to this admission (e.g., whether or not a PTCA was performed on this admission). These "Yes/No" data elements were also plagued by large numbers of missing values. As in the case of creatinine, CCMRP considered several alternative ways of handling this problem and ultimately decided to assume that whenever a value was not reported for these data elements that the value is "No." The data elements handled in this fashion are:

- Hypertension
- Dialysis
- Diabetes

- Peripheral Vascular Disease
- Cerebrovascular Disease
- Ventricular Arrhythmia
- Myocardial Infarction (ever)
- PTCA on Current Admission
- Chronic Obstructive Pulmonary Disease
- Congestive Heart Failure

Height and weight were too inconsistently coded to be used for analysis. Body Mass Index (BMI) or Body Surface Area (BSA) had been expected *a priori* to be important in our final logistic regression model, but because both height and weight are needed to calculate BMI and BSA, a missing or suspicious value in either element invalidates the entire calculation. Even when both data values were simultaneously available, detailed examination of the data submitted suggested the confounding of two types of errors: first, a failure to convert pounds and inches into metric kilograms and centimeters; and second, a possible switch where heights (in centimeters) may have been entered as weights (in kilograms) and vice versa.

Table F–1 shows the patient–level data elements (excluding height and weight) as they were distributed in the collected or raw data set. As can be seen from this table (and noted above), about one–third of all cases were submitted with missing creatinine values (9,937 of 30,814).

Table F–1: SUMMARY OF 1997–1998 RAW DATA SUBMITTED

30,814 total isolated CABG cases submitted by 82 hospitals

Status	Sex	Race	Hypertension	Dialysis	Diabetes
Alive:30012	Female: 8463	White:23531	No: 9866	No:26296	No:20453
Dead: 802	Male:22334	NonWhite: 7078	Yes:20848	Yes: 531	Yes:10216
	NA's: 17	NA's: 205	NA's: 100	NA's: 3987	NA's: 145

Periphvasc	Cerebrovasc	VentArrhythmia	COPD	PTCA
No:26482	No:25849	No:22741	No:26578	No:11718
Yes: 4195	Yes: 3239	Yes: 1594	Yes: 4058	Yes: 1153
NA's: 137	NA's: 1726	NA's: 6479	NA's: 178	NA's: 17943

CoMorbid	Prior Ops	MI	Angina	CHF
0:14199	0:28626	No:15613	None: 3136	No:25149
1:11110	1: 1988	Unknown: 959	Stable: 9821	Yes: 4975
2: 4071	2: 176	21+: 6606	Unstable:17719	NA's: 690
3: 1183	3+: 24	7+: 1267	NA's: 138	
4: 224		1+: 5012		
5: 26		0–1: 1108		
6: 1		NA's: 249		

NYHA	CCS	Acuity	LM Stenosis	Disease Type
I:14154	I: 2262	Elective:15190	<50%: 4910	Single: 1715
II: 4016	II: 5098	Urgent:13022	51–70%: 3109	Double: 5769
III: 5413	III:10590	Emergent: 1988	71–90%: 2101	Triple+:22802
IV: 3650	IV:11147	Salvage: 162	91+%: 802	LM Only: 313
NA's: 3581	NA's: 1717	NA's: 452	NA's:19892	NA's: 215

Mitral	Quarter	Age	Creatinine	Eject Fraction
None: 7235	1997–1: 3029	Min: 18.00	Min: 0.10	Min: 1.00
Trivial: 1060	1997–2: 3033	Mean: 66.07	Mean: 1.32	Mean: 53.87
Mild: 1136	1997–3: 2828	Median: 67.00	Median: 1.00	Median: 1.0055.00
Moderate: 473	1997–4: 2918	Max: 96.00	Max: 202.00	Max: 98.00
Severe: 104	1998–1: 4766	NA's: 14	NA's: 9937	NA's: 2866
NA's:20806	1998–2: 4759			
	1998–3: 4661			
	1998–4: 4820			

NA indicates that the data were missing.

Other data elements with even larger numbers of missing values include mitral insufficiency (20,806 missings), degree of stenosis of the left main coronary (19,892 missings), and a notation of whether or not a PTCA had been performed on the current admission (17,943 missings). Table F–3 summarizes the data after transformation and recoding, and prior to analysis.

Data Exclusions. Not all data submitted to CCMRP are included in this analysis. Notably, the data cleaning stage identified hospitals whose submissions showed unusually large numbers of missing values for potentially important explanatory factors. In consultation with these facilities, CCMRP staff were able to clarify and resolve many problems prior to analysis. Nonetheless, some unresolvable data problems remained and staff excluded from this analysis all or part of the data from two hospitals. In one of these two facilities (N.T. Enloe), the number of comorbidities appeared to be largely under–reported. In the other (St. Joseph of

Orange), there was a clear improvement in the completeness of reporting for important factors in 1998 compared to 1997. For both hospitals, the inclusion of large amounts of incomplete data would have made it impossible to distinguish between the quality of their care and the quality of their data. Worse, the inclusion of poor quality data from these two hospitals could have biased the model for all other hospitals in our data set. Accordingly, CCMRP omitted from further analysis all of Enloe's and St. Joseph of Orange's data for 1997. Additionally, because CCMRP is a voluntary program, a few hospitals withdrew prior to this analysis. While we analyzed data from 82 hospitals to compute the risk–adjustment model, three hospitals withdrew from the program after the analysis was completed but before this report was finished. No unusual patterns of incompleteness were observed among the data from these three hospitals so their inclusion in our analysis should not result in a biased model even though they declined to be identified in our report.

Audit of Hospital Data. After the preliminary data cleaning and analyses were completed, CCMRP developed and implemented an audit process meant to check the quality of the data submitted for 1998. CCMRP contracted with the Health Services Advisory Group (HSAG) to conduct the independent, external audit. HSAG is an Arizona–based peer–review organization with prior experience abstracting cardiovascular information from medical records. Six RN abstractors from HSAG attended a training class in which we used the same training materials that were used to train participating hospitals in data collection.

CCMRP selected for review all hospitals that were determined to be outliers (i.e., either higher than or lower than expected mortality rates based on a preliminary analysis of the 1997–1998 data), plus "near–outliers" on both ends of the spectrum. These near–outliers fell within the "no different than expected group." Two hospitals that had originally submitted data for analysis refused audit, a condition of participation; those hospitals were removed from our program and their data were dropped from further analysis.

HSAG abstractors attempted to review 40 charts on–site at each of 26 participating hospitals; as is the case in many hospitals, not every chart could be reviewed at the time when the auditors were present. A total of 1,006 total charts were reviewed from these 26 hospitals. Because this was CCMRP's first round of data checking, the main goal was to learn about the variability of coding and coding problems. Accordingly, these 40 charts per site were not chosen randomly but rather to highlight potential coding problems. Thus, the chart review can be thought of as an extended pilot test for future audits (recall that for the combined 1997–1998 data set, the overall in–hospital mortality rate was about 2.6%; had we chosen the cases for review randomly we would have expected about one death per hospital among our review set). To maximize our "learning set," staff focused on complex cases where either the calculated risk was high based on the data submitted, or the patient died. An unfortunate result of this non–random selection of cases is that statistical inference on our conclusions becomes much more difficult.

The abstraction process included a 5.0% over–read of charts to ensure accuracy in coding among abstractors. The abstractors gathered data on a blinded basis from the medical records at each hospital. The abstractors focused their review only on the data elements in the risk model that had a significant impact on the eventual health outcome of patients. Table F–2 lists the variables checked by the HSAG abstractors.

Table F–2: LIST OF AUDIT VARIABLES ABSTRACTED FROM MEDICAL RECORDS

Date of Birth	History of Dialysis	PTCA on Current Admission	Left Main Stenosis %
Gender	History of Diabetes	New York Heart Association Class	Date of Discharge
Admission Date	History of Peripheral Vascular Disease	Presence of Angina	Status of Discharge
Surgery Date	History of Cerebral Vascular Disease	Type of Angina	Location of Discharge (Home vs. SNF)
Surgery Time	History of COPD	Status (Acuity)	Date of Death
Creatinine Prior to Surgery	Ventricular Arrhythmia	Ejection Fraction	Date of Catheterization
Date of Creatinine	Date of Ventricular Arrhythmia	Date of Ejection Fraction	Verification that Case was Isolated CABG
History of Hypertension	Number of Prior Operations with Cardio Bypass	Source of Ejection Fraction	

After the abstraction process, HSAG provided a raw data file to CCMRP. The audited data were then compared against what the hospitals originally submitted to CCMRP, both in a series of NxN tables for each variable for each hospital (so that we could calculate concordance statistics) and also in a multivariate way by comparing estimated risks for each of the 1,006 reviewed cases based on submitted and audited values. Note that simple concordance tables, while informative in pinpointing coding problems that need to be fixed, do not reflect the relative importance of each variable to the overall risk–adjustment. The multivariate comparison could do so in a straightforward way. For example, as we shall see later when we discuss the results of our multivariate logistic regression model, a discrepancy in whether a hospital recorded a patient on dialysis matters far less for risk–adjustment than does a discrepancy in operative acuity.

The analysis of the audit results revealed a few issues with the submitted data that led CCMRP to request that several hospitals re–submit their data. In particular, several hospitals appeared to confound the coding of NYHA Class for measuring CHF and the coding of CCS Class for measuring angina.

The main question CCMRP sought to investigate by the audit was whether the rating of hospital quality depended on coding practice. For example, did hospitals that appeared to be better–performers exhibit systematic "coding creep," and did poorer–performing hospitals appear that way simply because they did a poor job of coding the data elements? CCMRP observed no overall systematic pattern of misstatement (e.g., neither "coding creep" nor data understatement), and a comparison of predicted risks based on submitted versus audited data showed that for the 26 audited hospitals, there was no relationship between the average risk level and a hospital's rating. There does appear to be a tendency for poorer–performing hospitals to be "sloppier" (i.e., to have less agreement between what was submitted and what

was audited) than better–performing hospitals. Nonetheless, had we relied on the audited data to compute the risk–adjusted rate for these hospitals, we would not have changed our conclusions about the poorer performing hospitals.

Model Development

Modeling Approach. There are many ways to approach the modeling of CABG mortality, some of which are mentioned in the reference section. CCMRP's modeling approach is state–of–the–art consistent with modern statistical practice,[10] and can be summarized with these key points:

- Use of expert opinion to select data elements (i.e., we did not select explanatory factors by "stepwise" techniques or by using "p–values"). The previous section discussed the data elements we collected and analyzed.
- Replacement of missing data in a way that discourages "coding creep" (i.e., we do not do listwise deletion of cases with missing data). This is discussed directly below in **Handling of Missing Values.**
- Use of multivariate logistic regression to model risk, but we did not automatically presume factors will be linear in log–odds.
- Assessment of fit through cross–validation.

Handling of Missing Values. Of the 30,814 cases included in the risk analysis, age could not be determined for 14 cases. These cases were omitted from further analysis, reducing the working number of cases to 30,800. Consistent with standard practice, the entire data set was divided randomly into two parts, a "training set" used to develop the model and a "test set" to assess fit. Also consistent with standard practice, after a final model was chosen and tested, the coefficients were re–estimated from the entire data set. These are the coefficients shown in this document.

To determine the influence of missing data values and either to replace or impute values if possible, CCMRP performed several exploratory analyses of the test data set examining four different alternatives in handling the missing values.

In the first alternative, an initial model was estimated on the test data set via stepwise logistic regression using listwise deletion of rows with missing values (that is, if any value for any data element was missing from a case, the entire case was omitted); fortunately few of the data elements with large numbers of missing values survived the culling process to the final model.

[10] See, for example, Harrell (1998).

For the second alternative, CCMRP created a data set with missing values replaced with medians (or modal values for factor variables), and re–analyzed using the same stepwise logistic regression approach. For example, a missing value for "Race" was replaced with "White" (for those cases where race was recorded, 23,531 were listed as "White" and 7078 were listed as "Non–white"; accordingly, the 205 cases with missing race were assigned to "White"). Of note, "modal replacement" means that a missing value for NYHA CHF Class was replaced with Class I, but a missing value for CCS Angina Class was replaced with Class IV. Data elements for which a large fraction of assignments were made include: PTCA on current admission (labeled "PTCA"), degree of stenosis of the Left Main coronary artery ("LM"), and degree of mitral insufficiency ("Mitral"). Although very few missing assignments were made for the "Disease Type," note that "Triple vessel disease" is by far the most commonly reported type of coronary artery disease. After these missing data assignments were made, staff re–analyzed the data and compared them with the elements identified in the preceding step. The same variables survived to the final model, with coefficients of the same sign. Although this does not resolve the issue of missing variable bias, it is reassuring that missing data do not seriously affect the model (at least in a multivariate way). As we shall see later, of the explanatory factors included in the final logistic regression model, the two major elements with large numbers of missing values are creatinine and ejection fraction. Many (but not all) hospitals collected creatinine values only if they exceeded 2.0 mg/dl, so values under 2.0 at these hospitals were unobservable, or "censored." In addition, out of the entire data set of almost 31,000 cases, 12 cases were reported with creatinine values exceeding 20 mg/dl and an additional 45 cases with creatinine above 10 mg/dl. These 57 cases appear to be either mis–entered or true outliers (For example, several of the 12 cases with creatinine values like "202" or "106" probably result from keystroking a "0" rather than a ".", and that the actual values likely were 2.2 and 1.6, but in the latter case the value as easily could have been 10.6). For these 57 cases, staff truncated their values at 10 mg/dl (e.g., staff did not attempt to re–code "202" to "2.2"). Truncating these 57 cases had an enormous effect on the coefficient for creatinine, which increased by a factor of three.

As a third alternative, CCMRP replaced creatinine values with a normal value (1.0 mg/dl) for these censored or missing cases. Similarly, missing values for ejection fraction were replaced with a preliminary guess at a "normal" value (60%). In addition, eight cases were observed with ejection fraction below 15%, and these were also replaced with a value of 60%. Stepwise logistic regression models were then re–estimated with similar data elements surviving to a final model, and surprisingly little change in the coefficients except for creatinine.

A fourth alternative, and the one ultimately recommended by our advisory committee, is to replace missing values with the lowest risk category for each data element (based on the test data set). Compared to the second alternative, this means that missing CCS Class is replaced with category III, and missing Angina is replaced with "Stable." This is the alternative that was chosen. The CCMRP Technical Advisory Panel recommended adopting this approach to replacing missing data because it would be consistent with the missing data practices of other large bypass graft reporting systems and would give hospitals a strong incentive to submit complete data to ensure full credit for more severely ill patients.

Table F–3: SUMMARY OF 1997–1998 DATA ANALYZED*

30,800 total isolated CABG cases submitted by 82 hospitals

Status	Sex	Race	Hypertension	Dialysis	Diabetes
Alive:30012	Female: 8463	White:23736	No: 9866	No:30283	No:20598
Dead: 802	Male:22351	NonWhite: 7078	Yes:20948	Yes: 531	Yes:10216
Periphvasc	**Cerebrovasc**	**VentArrhythmia**	**COPD**	**PTCA**	
No:26619	No:27575	No:29220	No:26756	No:29661	
Yes: 4195	Yes: 3239	Yes: 1594	Yes: 4058	Yes: 1153	
CoMorbid	**Operation**	**MI**	**Angina**	**CHF**	
0:14199	1st:28626	No:15862	None: 3136	No:25839	
1:11110	2nd: 1988	Unknown: 959	Stable: 9959	Yes: 4975	
2: 4071	3rd: 176	21+: 6606	Unstable: 17719		
3: 1183	4+: 24	7+: 1267			
4: 224		1+: 5012			
5: 26		0–1: 1108			
NYHA	**CCS**	**Acuity**	**LM Stenosis**	**Disease Type**	
I: 17735	I: 2262	Elective: 15642	<50%: 24802	Single: 1715	
II: 4016	II: 5098	Urgent: 13022	51–70%: 3109	Double: 5769	
III: 5413	III: 11307	Emergent: 1988	71–90%: 2101	Triple+:23017	
IV: 3650	IV: 11147	Salvage: 162	91+%: 802	LM Only: 313	
Mitral	**Quarter**	**Age**	**Creatinine**	**Eject Fraction**	
None:28041	1997–1: 3029	Min: 18.00	Min: 0.10	Min: 15.00	
Trivial: 1060	1997–2: 3033	Mean: 66.07	Mean: 1.18	Mean: 53.87	
Mild: 1136	1997–3: 2828	Median: 67.00	Median: 1.00	Median: 55.00	
Moderate: 473	1997–4: 2918	Max: 96.00	Max: 10.00	Max: 98.00	
Severe: 104	1998–1: 4766				
	1998–2: 4759				
	1998–3: 4661				
	1998–4: 4820				

*Note: The 30,800 cases are those that remain after dropping 14 cases with missing age and imputation of missing values.

Logistic Regression Models: Although there are many valid approaches to modeling binary outcomes (like survivorship or death), the most common and widely accepted method in use today is multivariate logistic regression. CCMRP relies on this approach, supplementing it with generalized additive models.[11] Additionally, to help summarize the data and identify interactions among the factors, CCMRP uses tree models, a recursive partitioning technique.[12]

Table F–4 summarizes a logistic regression model based on data with the missing values for creatinine and ejection fraction replaced as described above, and includes all data elements. The table shows an overall multivariate logistic summary of all variables being considered, and is often used as a starting point for variable selection using stepwise or other similar techniques.

[11] Logistic regression is a type of generalized linear model, or GLM. Generalized additive models are an extension of GLM's that allow examining nonlinear transformations of the explanatory factors.

[12] For a complete discussion of these statistical techniques, see Hastie and Tibshirani (1990) for an introduction to generalized additive models; Zhang and Singer (1999) for recursive partitioning trees; and Collet (1991) or Hosmer and Lemeshow (1989) for multivariate logistic regression models.

Table F-4: CCMRP 1997–1998 Logistic Regression Model

Explanatory Factor	Coefficient	Std. Error	t–value	Odds Ratio	Missing Variable Assignment
(Intercept)	–7.206	0.411	–17.512		
Age (in years)	0.044	0.004	**10.812**	1.05	Case Excluded
Sex					
Female	Reference				
Male	–0.401	0.080	**–5.005**	0.67	Male
Race					
White	Reference				White
Non–white	0.203	0.088	**2.294**	1.23	
Creatinine (mg/dl)	0.214	0.039	**5.433**	1.24	1.0; Truncated at 10
Hypertension	0.075	0.087	0.866	1.08	No
Dialysis	–0.029	0.275	–0.105	0.97	No
Diabetes	0.142	0.080	1.776	1.15	No
Peripheral Vascular Disease	0.435	0.091	**4.800**	1.54	No
Cerebrovascular Disease	0.244	0.101	**2.410**	1.28	No
Ventricular Arrhythmia	0.337	0.123	**2.737**	1.40	No
COPD	0.275	0.094	**2.914**	1.32	No
Operative Incidence					
First	Reference				First Operation
Second	0.674	0.118	**5.733**	1.96	
Third	1.354	0.276	**4.901**	3.87	
Fourth or Higher	1.823	0.660	**2.763**	6.19	
Myocardial Infarction					
None	Reference				None
Yes, but When Unknown	0.156	0.196	0.797	1.17	
21+ Days ago	0.028	0.105	0.263	1.03	
7–20 Days ago	–0.227	0.198	–1.145	0.80	
1–6 Days ago	0.237	0.107	**2.211**	1.27	
Within 1 day	0.876	0.150	**5.831**	2.40	
PTCA on This Admission	0.220	0.156	1.411	1.25	No
Angina					
None	Reference				
Stable	–0.369	0.137	**–2.691**	0.69	Angina Stable
Unstable	–0.256	0.129	**–1.977**	0.77	
NYHA CHF Class					
I	Reference				NYHA Class I
II	0.506	0.122	**4.141**	1.66	
III	0.549	0.109	**5.037**	1.73	
IV	0.769	0.102	**7.530**	2.16	
CCS Angina Class					
I	Reference				
II	0.178	0.192	0.927	1.19	
III	0.070	0.173	0.404	1.07	CCS Class III
IV	0.211	0.175	1.203	1.23	

Table F-4: CCMRP 1997–1998 Logistic Regression Model (cont.)

Explanatory Factor	Coefficient	Std. Error	t–value	Odds Ratio	Missing Variable Assignment
Acuity					
Elective	Reference				Elective
Urgent	0.221	0.090	**2.449**	1.25	
Emergent	0.743	0.136	**5.482**	2.10	
Salvage	2.806	0.218	**12.860**	16.55	
Ejection Fraction (%)	–0.012	0.003	**–4.393**	0.99	55; Truncated at 15.0
Left Main Stenosis					
0–50%	Reference				0–50%
51–70%	–0.015	0.126	–0.117	0.99	
71–90%	0.233	0.130	1.786	1.26	
91+%	0.525	0.153	**3.426**	1.69	
Type of Coronary Disease					
Single Vessel	Reference				Single Vessel Disease
Double vessel	–0.176	0.181	–0.974	0.84	
Triple or More	0.069	0.160	0.433	1.07	
LM Only disease	0.447	0.359	1.244	1.56	
Mitral Regurgitation					
None	Reference				None
Trivial	0.506	0.158	**3.203**	1.66	
Mild	0.247	0.151	1.638	1.28	
Moderate	0.612	0.192	**3.187**	1.84	
Severe	0.898	0.345	**2.598**	2.45	

Age, ejection fraction, and creatinine were entered as continuous variables; the other variables were entered as ordered factors. For the variables entered as ordered factors, the coefficients should be compared to the reference category (for example, we show coefficients for NYHA Classes II, III, and IV; those coefficients are compared to the reference category of NYHA Class I). Bolded t–values indicate the coefficient for that variable is statistically significant at the 0.05 level.

The model shown above in Table F–4 is the result of a logistic regression where the outcome variable is in–hospital mortality. Age, ejection fraction, and creatinine have been entered as continuous variables; the other variables have been entered as ordered factors. Logistic regression coefficients reveal the contribution of each data variable to the logarithm of the odds (log–odds) of in–hospital mortality; thus, a coefficient on age of 0.044 means that an increase in one year of age is associated with an increase of 0.044 in the log–odds of in–hospital mortality. For the variables entered as ordered factors, the coefficients should be compared to the omitted category (for example, we show coefficients for NYHA Classes II, III, and IV; those coefficients are compared to the omitted category of NYHA Class I).

Logistic regression models relate the probability of death (or, more accurately, the log–odds of death) to a number of explanatory factors, such as the age of the patient, the amount of creatinine in the blood, or whether this is the first cardiac operation this patient has undergone. For each explanatory factor, CCMRP includes columns that list the coefficient (or weight) of the explanatory factor, its standard error, the t–value, and an odds ratio. Of note, although several of the variables do not appear to be "statistically significant" (as determined

by the t–value), almost all of the coefficients appear with the sign that clinical judgment predicted.

Table F–4 can be thought of as a summary of the data CCMRP staff analyzed, and it may be helpful to explain how to interpret the table. It is important to understand that the table shows the results from a multivariate logistic regression, and therefore describes the relationship between in–hospital mortality and each explanatory factor after taking into account each of the other factors.

The **coefficient** of the explanatory factor measures how much the probability of in–hospital death (the log–odds) is affected if a patient has that factor (for categorical factors like whether the patient has diabetes). If the value is positive, it means that having that factor or characteristic is associated with an increased risk of death compared to not having it (after taking into account the effect of all of the other factors). If it is negative, having that factor or characteristic is associated with a lower risk of death compared to not having it. (Some articles refer to a characteristic with a negative coefficient as having a "protective" effect. We avoid that confusing and misleading usage). The larger the value is (whether positive or negative), the more effect this factor has on the risk of dying. For example, notice that the value of peripheral vascular disease is 0.435. This value is positive, so it means that having peripheral vascular disease is associated with an increased risk of dying in–hospital for CABG patients compared to not having the disease. On the other hand, notice that male has a value of –0.401. Since this value is negative, it means that in these data males have a lower probability of dying in–hospital than females even after taking into account all other factors. For continuous factors, like age or the creatinine level, the coefficient measures how much a one unit increase in that factor (either years of age or mg/dl of creatinine) affects the log–odds of death.

Another way of assessing the strength of each factor is to examine the column labeled **odds ratio**. The odds ratio is the antilogarithm of the column labeled "coefficient," but is often more familiar to those in the health sciences. The larger the odds ratio, the larger the impact that factor has on the risk of dying. An odds ratio close to 1.0 means that the effect of the factor is close to neutral. For example, notice that the odds ratio for peripheral vascular disease is 1.54. This means that in these data the odds of dying in–hospital if the patient has peripheral vascular disease is about 1.54 times higher than if the patient did not have it. Being male has an odds ratio of 0.67, and this means that the odds that a man will die in–hospital after CABG surgery is about 0.67 times as high (i.e., about two–thirds as much) as for a woman.

The column labeled **t–value** is a measure of the statistical significance of the coefficient for that factor. When the t–value is large (whether positive or negative), it indicates a fairly large amount of confidence that the effect of the factor is real. If it is small, we have much less confidence that the contribution of the factor is not spurious. A common (and commonly misunderstood) rule–of–thumb for interpreting this column is that an absolute t–value larger than 2.0 indicates that the effect of the factor is real. Note that the t–value for the male explanatory factor is –5.005. This is larger (in absolute value) than 2.0, and thus suggests even after accounting for all of the other listed variables, the sex of the patient is a statistically significant factor in explaining in–hospital mortality for CABG patients.

Not all explanatory factors in the model have t–values larger than 2.0. For example, the t–values for CCS angina Class and the type of coronary artery disease (single vessel, double, triple or more, or left main only) are all quite small. At least in these data, neither type of coronary disease nor CCS Class for measuring angina is a reliable predictor of in–hospital mortality. Note that a small t–value does *not* mean that factor has no effect on in–hospital mortality—it means that its effect, if any, is not reliably estimated.[13] In addition, the variable ought to be marked as significant or insignificant, not the coefficient. This distinction becomes clearer when one recognizes that we estimate separate coefficients for different levels of several variables that take on more than simple Yes/No values, such as for myocardial infarction and the degree of congestive heart failure ("NYHA CHF Class"). Although the individual coefficient for "MI: Yes, but when unknown" is marked with a t–value that one could interpret as saying that the coefficient is not distinguishable from zero in a statistical sense, the entire "MI" variable is decidedly significant. The only variables that appear entirely unhelpful are CCS angina Class, the type of coronary artery disease ("left main disease only"), dialysis, and hypertension. On the borderline are diabetes and especially "PTCA on this admission," which has a large effect but whose statistical reliability may be undermined by small sample size since its occurrence is rare.

Inclusion of Variables. CCMRP's approach to the inclusion of important variables is different enough from usual practice to warrant a note. It is common in other studies to include large numbers of candidate variables at an early analytical stage, and to go through a winnowing process to reduce the number of predictor variables to a manageable few. Methods such as stepwise regression have become popular because of their ability to do so in an automated way. CCMRP did not seek a model with a primary focus on parsimony. Clinical experts have already identified the candidate variables (Jones et al., 1996) that should be included. Rather, our goal is to find a model that predicts well, and we concern ourselves with whether the inclusion of a statistically "non-significant" coefficient trades off too much bias in favor of smaller variance. Winnowing down the variable list based on t-values (or similar measures) is where models often get into trouble with over–fitting. For example, the t-value on "71%-90% stenosis of the left main coronary artery" is "only" 1.79, but the effect is large, and it is consistent not only with clinical theory but also with the values below and above it. Clearly, in the context of the whole variable, it is important, but strict adherents of the 5.0% statistical significance rule would eliminate this variable from explanatory or predictive models.

Because this technical appendix focuses more on our analytical methods rather than the results, only an abbreviated discussion of our findings appears here. Nonetheless, a few of the more interesting observations are these:

- Age, acuity (i.e., how urgent the operation was), ejection fraction, and operative incidence are very important risk–model variables.
- Even after controlling for all other variables, sex appears to have a statistically significant effect, with males having about one–third lower mortality. There is some suggestion in the literature that sex may be a proxy for body size; unfortunately,

[13] This is particularly true for binomial GLM's when the fitted probabilities are close to zero (as occurs here) or one.

although we attempted to collect height and weight in order to construct an index of body mass, the data we received were plagued with either missing values or the apparent confusion of metric (kilogram and centimeter) and English (pound and inch) units. We intend to focus on this issue in our next series of training sessions and hope to include this variable in future analyses.

- After accounting for creatinine levels, dialysis appears to have no additional explanatory power. That is, even if a dialysis patient has higher creatinine levels than the average patient, once one knows that level the fact that the patient is on dialysis appears to add no additional information. This observation may seem odd to readers who are more familiar with binary (rather than multivariate) analyses particularly since we estimate the coefficient on dialysis to be very slightly negative. It is often the case that a continuous variable like Creatinine will "carry" more information than a discrete binary variable like Dialysis: yes or no?
- Patients with no angina have higher risk of in–hospital death than patients reported as having either "stable" or "unstable angina." Patients with no angina are unusual in that the majority of patients undergoing isolated CABG surgery have either "stable" or "unstable angina." Table F–1 (**Technical Appendix**) shows that only about 10% of the patients are classified as having "angina, none."
- The NYHA Class, used to measure the degree of congestive heart failure, appears to make a "natural" split between NYHA Class I and NYHA Classes II, III, and IV.
- CCS Class, used to measure the degree of angina, appears not to have much explanatory power. We conjecture that because the majority of CABG patients suffer from Class III or Class IV anginal pain, there is insufficient variability in these data to distinguish mortality differentials, i.e., since patients are likely to be selected for surgery based on the degree of angina, once we have restricted our data to patients who have had CABG surgery the degree of angina provides no additional explanatory power.
- The coefficients on the MI variable seem to indicate that an MI more than one week before the CABG procedure has an effect on risk indistinguishable from no MI at all, even after controlling for the acuity of the operation.
- Moderate amounts of stenosis of the Left Main coronary artery (up to about 70% stenosis) do not appear to have much of an elevating effect on the risk of in–hospital mortality. Stenosis beyond this level appears to have a much larger effect. Note that the usual analysis might conclude that a 75% stenosis is statistically indistinguishable from no stenosis because the t-statistic is less than 2.0 (it is 1.79). As an interesting sidenote, for the year 2000, the Society of Thoracic Surgeons Adult Cardiac Database will be collecting data only on whether stenosis of the left main coronary artery exceeds 50% and will no longer collect data on how much beyond 50% a stenosis is.
- Of the comorbidities we collect, peripheral vascular disease appears to have the largest effect.

- The number of vessels affected with coronary disease appears to have an effect in the hypothesized direction, but the effect is not statistically distinguishable from no effect.
- While "moderate" and "severe" mitral regurgitation appear to have effects as would be expected from a clinical standpoint, "mild" regurgitation is anomalous in appearing to have a lesser effect than "trivial." This may result from coding confusion between these two categories and CCMRP intends to focus on this distinction in future data collection training sessions.
- It may be possible to collapse several of the factor levels, such as for MI or mitral regurgitation, into fewer categories.

Model Fit and Validation

How can we be sure that the model estimated above is both a good summary of the data and also can be a valid basis for risk–adjustment? Earlier sections of this appendix addressed issues of data validity (see **Audit of Hospital Data**, and **Handling of Missing Values**) and content validity (**Data**). Structural validity is discussed in part in the next section, **Alternate Models**. In this section, we focus on discrimination and calibration of our logistic regression model.

Discrimination. Models that distinguish well between patients who die and those who survive are said to have good discrimination. A commonly used measure of discrimination is the c–index (also known as the c–statistic or the area under the ROC curve). The c–index ranges between 0.0 and 1.0, with higher values indicating better discrimination. For the model in Table F–4, the c–index is 0.803. In comparison, c–indexes reported in other published studies of CABG mortality that use logistic regression (including those from New York and the STS) range from about 0.74 to about 0.82. We conclude that the CCMRP model discriminates as well as these studies. For risk–adjustment purposes, it is generally thought that discrimination is a less important measure of model fit than calibration.[14]

Calibration. Calibration refers to the ability of a model to match predicted and observed death rates across the entire spread of the data. A model where the numbers of observed deaths align well with the numbers of deaths predicted by the model demonstrates good calibration. Because good calibration is essential for reliable risk–adjustment, we focus most of our attention on model fit on calibration.

A common measure of calibration is Hosmer and Lemeshow's chi-square statistic, which compares observed and predicted outcomes over deciles of risk. Although Table F–5 below shows the data necessary to calculate the Hosmer–Lemeshow $\chi 2$ (the test statistic is 13.15 with 8 df, p=.10, indicating that our model hews to the data moderately well), in recent years Hosmer and Lemeshow have begun to reassess this test statistic because it is sensitive to cutpoints and the number of groups.[15] Accordingly, of more general interest is direct examination both of the table and of the entire calibration distribution.

[14] The opposite is generally thought to apply in clinical or diagnostic settings, where discrimination is considered far more important than whether an overall model calibrates to the data well.

[15] See, for example, Hosmer, Hosmer, le Cessie, and Lemeshow (1997).

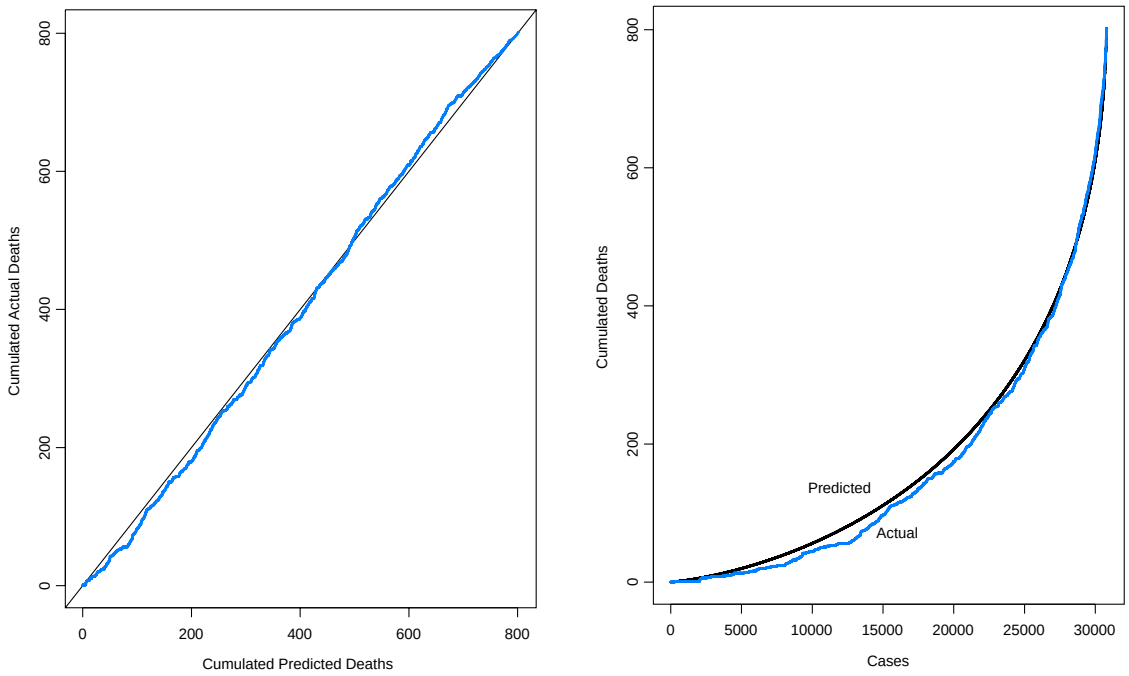
Table F–5 provides a summary comparison of our model to the data. There are 30,800 patients in our data set, so the first row of the table reports that of the decile of patients at lowest risk of in–hospital death based on our model (i.e., the 3,080 patients whose predicted risk of dying ranged from 0 to 0.5%), only eight died. Our model predicted that 10.1 of the patients in this decile group would have died. In other words, for this group of more than 3,000 patients (more than the average California cardiac surgery program would see in a decade), we observed 8 deaths and predicted 10.1. This means that our model predicted very slightly more deaths (2 deaths more) for this lowest risk group than actually occurred. On the other hand, the last row of Table F–5 says that of the "riskiest" decile of patients, 369 died, while our model predicted 366.8 deaths from this group (2.2 deaths fewer). Although the calibration appears good overall, our model appears to slightly "over predict" mortality for the least risky cases compared to the most risky cases (i.e., the model appears slightly to underfit the data), but not at a statistically significant level.

Table F–5: MODEL CALIBRATION

Decile Group	Predicted Risk of Dying	Actual Deaths	Predicted Deaths	Difference in 3,080 Patients
1	0 – 0.44%	8	10.1	–2.1
2	0.44% – 0.64%	10	16.7	–6.7
3	0.64% – 0.84%	19	22.8	–3.8
4	0.84% – 1.08%	19	29.5	–10.5
5	1.08% – 1.36%	50	37.4	+12.6
6	1.36% – 1.74%	46	47.4	–1.4
7	1.74% – 2.31%	58	61.9	–3.9
8	2.31% – 3.20%	85	83.6	+1.4
9	3.20% – 5.33%	138	126.0	+12.0
10	5.33% – 90.12%	369	366.8	+2.2

The following two graphs help explain the calibration of the CCMRP risk model. The first graph (below left) shows a plot of the cumulative number of predicted deaths based on our model against the number of actual deaths. The closer our predictions are to the actual experience, the closer the curve will be to the superimposed 45-degree line. Overall, the predictions appear to track the actual observed deaths well, but with the slight "underfit twist" noted above.

The right-hand graph plots the Actual and Predicted number of cumulative deaths against all 30,800 cases. The "smooth" curve summarizes the CCMRP predictions, while the slightly jagged curve shows the actual deaths. Because the model calibrates to the data well, the two curves lie close to each other. In addition, both curves are relatively flat toward the left and increase rapidly toward the right, akin to so–called "exponential" curves, demonstrating that the majority of CABG surgeries are low in risk while most in-hospital deaths appear to be concentrated in a relative handful of higher–risk patients. Half of 30,800 (the number of total



cases in our analysis) is 15,400, and one can see from this graph that approximately 100 deaths occurred to the 15,000 patients of lowest risk (exactly 106 out of 15,400, for a median risk of in–hospital death of 1.4%), while the remaining 700 deaths were concentrated in the upper half of cases. Although the overall average in–hospital mortality rate following isolated CABG surgery is already a low 2.6%, it is perhaps even more impressive that the average risk of death for the less–risky half is 0.7%, emphasizing that modern CABG surgery is remarkably survivable. Note that, although not drawn in, a straight line connecting the lower leftmost point with the upper rightmost point identifies a "constant risk" line of 2.6%, and would emphasize how much improved our model is compared to unadjusted risk models.

Three features concerning calibration of the model emerge in the graphs and in Table F–5:

- The majority of cases exhibit low risk. Nonetheless, the range of predicted risks (from almost zero to 90%) seems adequately wide, suggesting that our model does well at covering the potential range of risks. This addresses the common belief that risk models cannot be used for high risk patients.
- The model fits very well in the higher risk categories. For patients whose predicted risk exceeds 5.33%, the number of predicted deaths almost exactly matches the number of deaths actually observed, and the total number of predicted deaths for predicted risks above 1.36% is quite close to the observed. This suggests that risk–adjustment for higher risk patients is quite good. **The CCMRP concludes that this model does not provide an incentive for hospitals to exclude high–risk patients from appropriate surgeries in order to improve their risk–adjusted rates.**

- There may be slight evidence that the model over–adjusts at the lowest risks, but this evidence is statistically non–significant and the over–adjustment is relatively small.

Alternative Models

An examination of the coefficients in Table F-4 reinforces that (almost) all of the explanatory factors have effects in the directions expected by clinical experience, though some do not have t–values large enough for these effects to be reliably estimated. In particular, CCS Class, type of coronary artery disease, and some of the co–morbid conditions (hypertension and dialysis) fall into this category. Although the common analytical approach is to drop "non–significant" explanatory factors, modern statistical practice frowns on this, in part because ad hoc selection of factors invalidates tests of fit, particularly the discrimination and calibration tests described in the previous section.

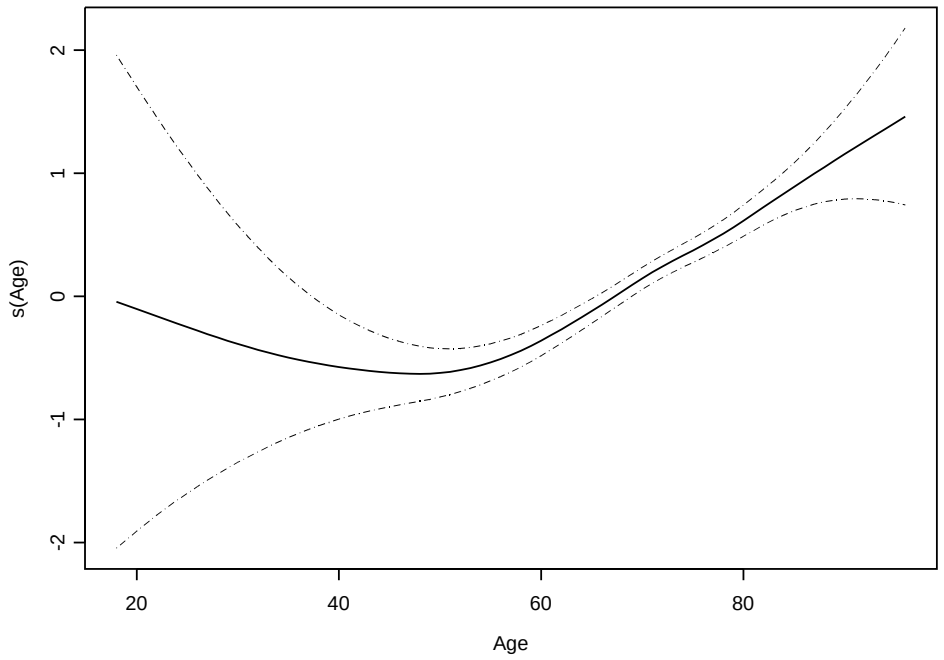
Nonetheless, CCMRP examined a series of alternative models which may be helpful in developing a future model. In that spirit, staff formed a series of two–way interaction terms and used forward stepwise regression to cull through the terms. In addition to the variables noted above (CCS Class, coronary disease type, and some of the comorbidities), no single two–way term survived the stepwise selection.

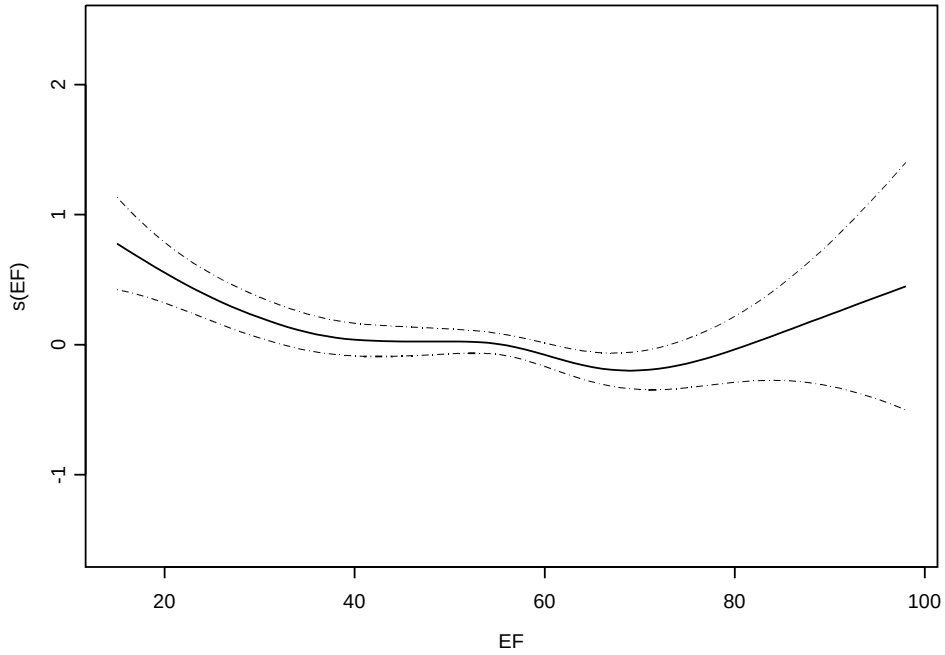
Staff then constructed a comorbidity index by summing the number of "Yes" responses for each patient for the six comorbidity variables (dialysis, diabetes, peripheral vascular disease, cerebrovascular disease, ventricular arrhythmia, and chronic obstructive pulmonary disease), implicitly giving each an equal weight (similar indices have been examined by others). The index was then entered into a new analytical formulation, both in linear and polynomial formulations (since the index is a linear combination of the individual comorbidities, it was not entered as a linear term simultaneously with the comorbidities themselves). As will be seen below, this constructed index turns out to be a useful predictor, especially in the classification tree model.

To investigate whether the logistic regression model would benefit from transformations of the continuous data variables, staff analyzed a series of **Generalized Additive Models** (GAM's), which allow for nonlinear (or "curved") relationships in the data. Although the GAM does marginally better than the regular logistic regression, its additional complexity was not judged worthy of further development for this analysis.

Two intriguing but inconclusive indications may be worth future investigation. Below, are partial residual plots for the GAM. They suggest:

- The effect of age on the log–odds of in–hospital mortality may be nonlinear, with a potential flattening below age 50 or 55; and
- The effect of ejection fraction on the log–odds of in–hospital mortality may also be nonlinear, with a potential flattening above (approximately) 60% or 65%.





If these results prove consistent, the functional conclusion is that CABG patients younger than about 50 do not get any additional protective effect from their age, nor do patients with ejection fractions much above "normal." The implication for risk–adjustment models is that both age and ejection fraction may be better modeled by using piecewise linear terms, with knots at about age 50 and ejection fraction about 65% (i.e., without a piecewise linear correction, logistic regression models like the one estimated in Table F–4 may slightly underestimate the effect on mortality of low ejection fractions and older age). An estimation

of such piecewise linear models showed these changes in the coefficient values with a (marginally) superior fit to the data. Nonetheless, it is premature to use such terms in our risk–adjustment model until further analysis is done.

In parallel to the logistic regression, but done entirely separately, another analytical approach was explored using a **Multivariate Classification Tree**, a recursive partitioning technique. A classification tree based on all data elements and all 30,800 cases was constructed. In tree–based analyses, binary splits are chosen by finding the best way to partition the data so that each new partition or "split" is as homogeneous[16] as possible and as different from the other split as possible. This splitting is continued until each final node is as homogeneous as desired–in theory, there can be 30,800 final nodes for the 30,800 cases, which is an unwieldy size. In practice, one chooses a tree of a workable size. Figure F–1 displays such a "working" tree, which prunes the less important splits at the bottom but keeps the more important splits at the top. The splits help identify the data elements that are important in achieving a good fit and almost the same variables show up in this tree analysis as in the stepwise logistic regression. The fact that two such different modeling approaches seem to identify the same important data elements is reassuring.

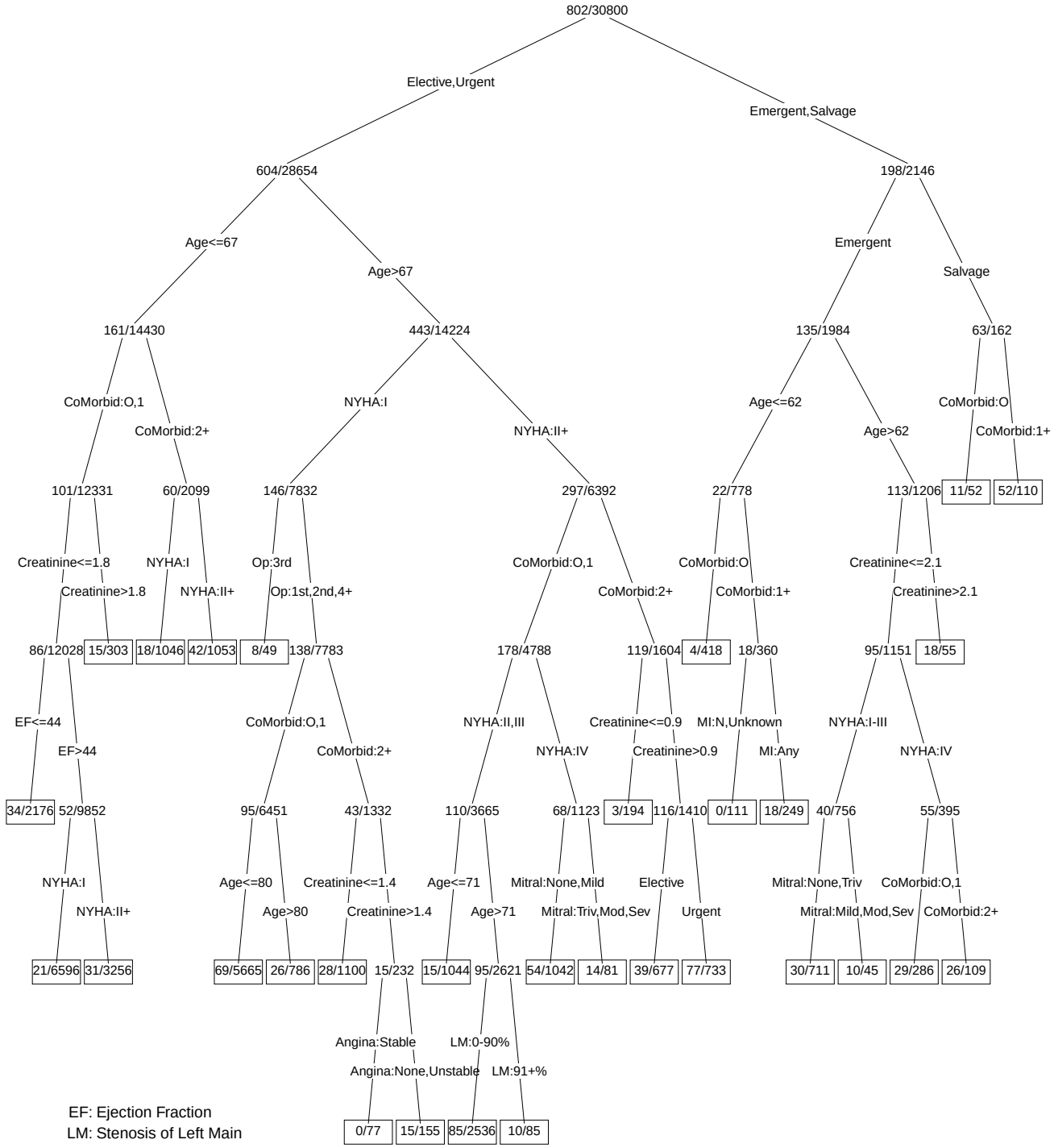
Figure F–1, the "working" tree, shows at its top an initial node labeled "802/30800." This indicates that of the 30,800 patients in our isolated CABG data set, 802 died in–hospital for an overall mortality rate of 2.60%. The tree also shows an initial split on acuity, with elective and urgent patients being separated from emergent and salvage patients. This means that of this entire data set, the single split that separates the data into two groups that are most different between groups and most alike within groups is the split in the data on acuity between "urgent" and "emergent." In essence, the single question that best splits patients into lower and higher risk groups is, "Is this patient's acuity either emergent or salvage?" The left branch of the tree (the elective/urgent branch) comprises 28,654 cases of the total 30,800 and that grouping is labeled as "604/28654" indicating 604 in–hospital deaths out of 28,654 cases (about 2.11%). The right branch of the tree is labeled "198/2146" and indicates that 198 deaths occurred to the 2146 cases whose acuity was either emergent or salvage (about 9.2%).

On the right of the tree, we see that the next split is once again on acuity, and it separates emergent cases (135/1984, or a mortality rate of 6.8%) from salvage cases (63/162, or a mortality rate of 38.9%). Further, the salvage node is split on number of comorbid conditions, with 0 to the left and 1 or more to the right. In these data, of those to be "salvage" but to have none of the listed comorbid conditions, only 11 of 52 died; of those who had any of the listed comorbidities, 52 of 110 died in–hospital. These last two nodes are boxed, indicating that there are further splits below this level, but we abridge the tree at this point since those splits are less important in improving overall tree fit than the splits shown elsewhere on the page.

In contrast to the “Salvage with some comorbid condition” node, notice that of the almost 6,600 patients who had elective or urgent acuity, were under age 67, had either no or only one comorbid condition, creatinine levels that were not too elevated, fairly normal ejection

[16] In this tree, homogeneity is measured by the deviance, which is closely related to the likelihood function; also commonly used in tree splitting is the misclassification rate. Of course, the exact split depends on the criterion but the qualitative conclusions we draw in this section do not.

FIGURE F-1: 1997-1998 CCMRP Isolated CABG Summary, Multivariate Classification Tree



EF: Ejection Fraction
LM: Stenosis of Left Main
MI: MI prior to CABG
OP: Operative incidence
CoMorbid: Comorbidities include Diabetes, Dialysis, Peripheral Vascular Disease, Cerebrovascular Disease, COPD, and Ventricular Arrhythmia
x/y : branches below this point continue, but are truncated to simplify structure

fraction, and low CHF category, only 21 died. Answers to only six questions (acuity, age, number of comorbidities, creatinine, ejection fraction, and CHF class) could be used to identify a group of patients comprising more than a fifth of the entire data set whose overall mortality rate was 0.3%, i.e., 99.7% of them survived to be discharged from the hospital.

A tree–based model like the one shown here could be used as the basis for a risk–adjustment model, but because statistical inference for tree–based models is still in its infancy it would be premature to do so. Rather, the tree serves as a particularly easy–to–grasp summary of the data. Not only does it provide a good sense of the importance of interaction among variables (for example, the tree suggests that congestive heart failure has more severe implications for older patients than it does for younger patients), but it also points out that the majority of CABG patients fall into relatively few risk "boxes" with very low probabilities of death. Although the mean in–hospital death rate in our data set is 2.60%, one can determine from the tree that the median risk of death for CABG patients is approximately 0.7%, which coincides with our previous estimate based on the logistic regression model. Happily, in California today the vast majority of CABG surgery cases are very low risk.

Hospital Risk–Adjusted Mortality Predictions

The logistic regression model in the previous section can be used to risk–adjust the observations collected from the 82 hospitals by calculating expected numbers of in-hospital deaths and comparing them to the observed numbers of deaths.[17] Tables F–6 and F–7 below show this comparison, arranging the hospitals first in alphabetical order, then in descending order of O/E ratio. Four hospitals show an observed death rate higher than the upper bound of the 95% confidence interval and thus are labeled as "Worse than expected," and three lower than the lower bound and are labeled "Better than expected."

To read this table, look at the observed to expected mortality ratio (O/E). If this number is higher than 1.0, it means that the hospital had more deaths than would have been expected given the health status of its patients. If the number is lower than 1.0, it means that the hospital had fewer deaths than would have been expected given the health status of its patients. However, **small differences in the O/E ratio are usually not significant**. The most important issue is that hospitals that have O/E ratios of less than or greater than one do not necessarily do better or worse than expected unless the result is statistically significant. Those hospitals where the difference between observed and expected death rates are significantly different are shown in bold type.

Total CABG cases submitted: This column reports the number of isolated CABG cases submitted to CCMRP for the 1997–1998 period. Some hospitals began submitting data to us in 1997, while others began in 1998, so we include the starting and ending dates for the data we received. Staff combined all data from all participating hospitals to construct our 1997–1998 risk adjustment model. The 1997–1998 data set for public reporting has almost 28,597 cases in it from 79 hospitals, making this report the largest ever public report on CABG outcomes.

[17] Three of the 82 Hospitals that submitted data for the 1997-1998 period withdrew from the program after the analysis was completed but prior to preparation of the report, leaving 79 hospitals that agreed to publicity report their results. However, data from all 82 hospitals was used to develop the risk-adjustment model.

The number of observed deaths: These are the actual number of in–hospital deaths submitted to CCMRP for isolated CABG patients during the 1997–1998 period. This number does *not* include patients who died after transfer or discharge from a hospital. There were 802 in–hospital deaths in our 1997–1998 risk–adjustment data set.

The number of expected deaths: The risk adjustment model was used to calculate the probability of in–hospital death for each one of the 30,800 cases (82 hospitals) in the 1997–1998 data set used to derive the risk–adjustment model. CCMRP staff then summed the probabilities for all cases at each hospital to get the number of in–hospital deaths we would expect given the case–mix of patient severities. For example, if a hospital had 150 patients, 100 of whom had a 1% probability of death, 40 of whom had a 4% probability of death, and 10 with a 9% probability of death, the total number of expected deaths would be 3.5 (i.e., (100)(1%) + (40)(4%) + (10)(9%) = 1 + 1.6 + 0.9 = 3.5 expected deaths). Note that the number of expected deaths can be a fractional number, unlike the number of observed deaths (which can only be a whole number).

The observed and expected death rates: Dividing the number of observed deaths for each hospital by the total number of cases produces the observed death rate for the 1997–1998 period. Dividing the number of expected deaths by the total number of cases produces the expected death rate. For example, if a hospital had 250 isolated CABG cases in 1997–1998, with seven actual in–hospital deaths, and an expected number of in–hospital deaths of 8.2, the observed death rate would be 7/250 = 2.8% while the expected death rate would be 8.2/250 = 3.28%. Note that the expected death rate is a measure of the average severity of illness of isolated CABG patients at a particular hospital: the higher the expected rate, the higher the average severity. The average death rate for the entire 1997–1998 data set is 802/30814 = 2.60%, so if the expected death rate is higher than 2.60% at a particular hospital, their isolated CABG patients tend to be higher risk than the overall population of CABG patients in our study.

The lower and upper bounds on the expected death rate: Assuming that the CCMRP risk adjustment model is correct, we can calculate the standard deviation of the number of expected deaths at each hospital. Because there is a great deal of variability in patient risks, the standard deviation is calculated based on the predictions of risk for each patient rather than using the average risk over all patients at each hospital. A lower confidence limit bound is calculated on our expected rate by subtracting twice the standard deviation from our expected rate, and a similar upper bound by adding twice the standard deviation to our expected rate. Two standard deviations (2SD) below and above the expected rate is an approximate 95% confidence interval. In general, when the upper and lower bounds on the expected death rate are close together, that means that the expected rate is fairly reliably estimated. **The width of the confidence interval depends both on the number of cases that a hospital submitted to us, and how widely differing the risks are for their isolated CABG patients.** A hospital that submitted many cases to the CCMRP will tend to have a narrower confidence interval than a hospital that did not, and the CCMRP will tend to have a more reliable idea of its overall performance.

The O/E ratio: The ratio of the observed to expected death rates produces the O/E ratio. This ratio is a quick method for assessing hospital performance. If a hospital had fewer actual

deaths than expected, its O/E ratio will be less than 1.0. If a hospital had more deaths than expected, its O/E ratio will be greater than 1.0. If, as in the previous example, the observed death rate was 2.8% while the expected death rate was 3.28%, the O/E ratio would be 2.8%/3.28% = 0.854.

Overall rating: The overall rating is a combination of overall performance (given by the O/E ratio) and how reliable that performance is (given by the lower and upper bounds on the expected death rate). All hospitals were split into three groups, "better than expected," "worse than expected," and "no different than expected." If a hospital's O/E ratio is less than one *and* its observed death rate is below the lower bound on the expected death rate, it means that CCMRP staff calculated its performance to be better than expected *and* we are fairly confident that our calculation was reliable. On the other hand, if a hospital's O/E ratio is greater than one *and* its observed death rate is above the upper bound on the expected death rate, it is rated as "worse than expected." If a hospital's observed rate is within the 2SD confidence interval, it means that we cannot reliably assign it to one of the other two groupings and it will be listed as "no different than expected."

Table F–6: Risk–Adjusted Results for CCMRP Hospitals, 1997–1998, Sorted Alphabetically

Name	Total CABG Cases Submitted	Number of Observed Deaths	Number of Expected Deaths	O/E Ratio	Observed Death Rate (%)	Lower 95% CI of Expected Death Rate (%)	Expected Death Rate (%)	Upper 95% CI of Expected Death Rate (%)	Overall Performance Rating (blank = no different than expected)
ALTA BATES MEDICAL CENTER	276	11	7.29	1.51	3.99	0.83	2.64	4.46	
ALVARADO HOSPITAL MEDICAL CENTER	298	16	10.71	1.49	5.37	1.51	3.59	5.68	
ANAHEIM MEMORIAL MEDICAL CENTER	130	4	3.08	1.30	3.08	0.00	2.37	4.89	
CALIFORNIA PAC MED CTR—PACIFIC CAMPUS	176	6	3.47	1.73	3.41	0.00	1.97	4.03	
CEDARS–SINAI MEDICAL CENTER	868	19	21.54	0.88	2.19	1.46	2.48	3.50	
CITRUS VALLEY MEDICAL CENTER–IC CAMPUS	430	16	14.35	1.12	3.72	1.65	3.34	5.03	
COMMUNITY MEM HOSP—SAN BUENAVENTURA	202	4	3.81	1.05	1.98	0.00	1.89	3.78	
DAMERON HOSPITAL	107	3	3.97	0.76	2.80	0.30	3.71	7.11	
DANIEL FREEMAN MEMORIAL HOSPITAL	173	2	3.86	0.52	1.16	0.01	2.23	4.44	
DESERT REGIONAL MEDICAL CENTER	122	5	2.91	1.72	4.10	0.00	2.39	5.12	
DOCTORS MEDICAL CENTER—SAN PABLO	169	3	7.28	0.41	1.78	1.42	4.31	7.21	
DOCTORS MEDICAL CENTER—MODESTO	451	11	8.22	1.34	2.44	0.57	1.82	3.07	
DOMINICAN SANTA CRUZ HOSPITAL—SOQUEL	272	10	7.84	1.28	3.68	0.98	2.88	4.79	
DOWNEY COMMUNITY HOSPITAL ▼	239	13	6.53	1.99	5.44	0.72	2.73	4.75	Worse than Expected
EL CAMINO HOSPITAL	52	1	2.14	0.47	1.92	0.00	4.11	8.96	
ENCINO TARZANA REGIONAL MEDICAL CENTER	145	2	7.17	0.28	1.38	1.36	4.94	8.53	
GLENDALE ADVENTIST MEDICAL CENTER	203	7	6.35	1.10	3.45	0.83	3.13	5.43	
GLENDALE MEMORIAL HOSPITAL AND HEALTH CTR	223	8	10.98	0.73	3.59	2.13	4.92	7.72	
GRANADA HILLS COMMUNITY HOSPITAL	142	4	2.13	1.88	2.82	0.00	1.50	3.52	
HOAG MEMORIAL HOSPITAL PRESBYTERIAN ★	496	9	17.98	0.50	1.81	2.03	3.63	5.22	Better than Expected
JOHN MUIR MEDICAL CENTER ▼	128	9	2.97	3.03	7.03	0.00	2.32	4.91	Worse than Expected
KAISER FOUNDATION HOSP—GEARY (S.F.)	992	21	18.58	1.13	2.12	1.05	1.87	2.69	
KAISER FOUNDATION HOSP—SUNSET (L.A.)	2302	31	37.66	0.82	1.35	1.12	1.64	2.15	
KAWEAH DELTA DISTRICT HOSPITAL	562	9	16.51	0.55	1.60	1.59	2.94	4.28	
LANCASTER COMMUNITY HOSPITAL	23	0	0.76	0.00	0.00	0.00	3.31	9.49	
LITTLE COMPANY OF MARY HOSPITAL	160	4	3.84	1.04	2.50	0.03	2.40	4.77	

★ Better than expected mortality rate, ▼ Worse than expected mortality rate.

Table F–6: Risk–Adjusted Results for CCMRP Hospitals, 1997–1998, Sorted Alphabetically

Name	Total CABG Cases Submitted	Number of Observed Deaths	Number of Expected Deaths	O/E Ratio	Observed Death Rate (%)	Lower 95% CI of Expected Death Rate (%)	Expected Death Rate (%)	Upper 95% CI of Expected Death Rate (%)	Overall Performance Rating (blank = no different than expected)
LONG BEACH MEMORIAL MEDICAL CENTER	378	7	12.01	0.58	1.85	1.42	3.18	4.93	
LOS ANGELES CO USC MEDICAL CENTER	146	4	2.87	1.39	2.74	0.00	1.96	4.20	
MARIN GENERAL HOSPITAL	94	2	1.74	1.15	2.13	0.00	1.85	4.59	
MEDICAL CENTER AT THE UCSF	141	7	3.95	1.77	4.96	0.29	2.80	5.30	
MEMORIAL HOSPITAL MODESTO	550	16	11.55	1.39	2.91	0.89	2.10	3.31	
MERCY GENERAL HOSPITAL	2565	32	38.37	0.83	1.25	1.03	1.50	1.97	
MERCY MEDICAL CENTER—REDDING	114	3	5.49	0.55	2.63	1.05	4.82	8.58	
MERCY SAN JUAN HOSPITAL ▼	408	17	7.92	2.15	4.17	0.60	1.94	3.28	Worse than Expected
METHODIST HOSPITAL OF SOUTHERN CALIFORNIA	428	17	14.26	1.19	3.97	1.64	3.33	5.02	
MILLS–PENINSULA MEDICAL CENTER	323	14	8.92	1.57	4.33	1.04	2.76	4.48	
MT DIABLO MEDICAL CENTER	561	20	15.91	1.26	3.57	1.49	2.84	4.18	
NORTHRIDGE HOSPITAL MEDICAL CENTER	301	9	8.91	1.01	2.99	1.04	2.96	4.88	
PALOMAR MEDICAL CENTER	349	13	11.08	1.17	3.72	1.40	3.18	4.95	
POMONA VALLEY HOSPITAL MEDICAL CENTER	527	18	13.11	1.37	3.42	1.19	2.49	3.79	
PRESBYTERIAN INTERCOMMUNITY HOSPITAL ▼	117	9	4.55	1.98	7.69	0.69	3.89	7.08	Worse than Expected
PROVIDENCE HOLY CROSS MEDICAL CENTER	114	3	2.70	1.11	2.63	0.00	2.37	5.19	
PROVIDENCE SAINT JOSEPH MEDICAL CENTER	232	3	3.74	0.80	1.29	0.00	1.61	3.25	
REDDING MEDICAL CENTER	1037	14	16.22	0.86	1.35	0.81	1.56	2.32	
RIVERSIDE COMMUNITY HOSPITAL	86	7	4.57	1.53	8.14	1.00	5.32	9.64	
SADDLEBACK MEMORIAL MEDICAL CENTER	175	9	8.03	1.12	5.14	1.52	4.59	7.66	
SALINAS VALLEY MEMORIAL HOSPITAL	135	2	3.88	0.52	1.48	0.08	2.87	5.67	
SAN ANTONIO COMMUNITY HOSPITAL	124	3	7.56	0.40	2.42	2.25	6.10	9.94	
SANTA BARBARA COTTAGE HOSPITAL	267	9	6.75	1.33	3.37	0.65	2.53	4.41	
SANTA MONICA—UCLA MEDICAL CENTER	45	2	1.25	1.60	4.44	0.00	2.78	7.64	
SCRIPPS MEMORIAL HOSPITAL—LA JOLLA	674	15	19.92	0.75	2.23	1.74	2.96	4.17	

★ Better than expected mortality rate, ▼ Worse than expected mortality rate.

Table F–6: Risk–Adjusted Results for CCMRP Hospitals, 1997–1998, Sorted Alphabetically

Name	Total CABG Cases Submitted	Number of Observed Deaths	Number of Expected Deaths	O/E Ratio	Observed Death Rate (%)	Lower 95% CI of Expected Death Rate (%)	Expected Death Rate (%)	Upper 95% CI of Expected Death Rate (%)	Overall Performance Rating (blank = no different than expected)
SEQUOIA HOSPITAL	483	18	21.36	0.84	3.73	2.67	4.42	6.18	
SETON MEDICAL CENTER	1249	18	22.21	0.81	1.44	1.04	1.78	2.52	
SHARP CHULA VISTA MEDICAL CENTER	531	23	18.94	1.21	4.33	2.01	3.57	5.12	
SHARP GROSSMONT HOSPITAL	133	1	2.34	0.43	0.75	0.00	1.76	4.02	
SHARP MEMORIAL HOSPITAL	304	4	5.24	0.76	1.32	0.25	1.73	3.20	
ST. BERNARDINE MEDICAL CENTER	405	11	14.40	0.76	2.72	1.76	3.56	5.35	
ST. FRANCIS MEDICAL CENTER	62	3	3.39	0.89	4.84	0.00	5.46	11.00	
ST. HELENA HOSPITAL AND HEALTH CENTER	419	8	11.27	0.71	1.91	1.15	2.69	4.23	
ST. JOHN'S HOSPITAL—SANTA MONICA	256	5	6.80	0.74	1.95	0.72	2.66	4.60	
ST. JOHN'S REGIONAL MED CENTER – OXNARD	90	2	2.91	.69	2.22	0.00	3.24	6.84	
ST. JOSEPH HOSPITAL—ORANGE	293	8	6.57	1.22	2.73	0.54	2.24	3.94	
ST. JOSEPH'S MEDICAL CENTER OF STOCKTON	610	20	17.31	1.16	3.28	1.55	2.84	4.13	
ST. JUDE MEDICAL CENTER	205	8	5.13	1.56	3.90	0.40	2.50	4.61	
ST. MARY MEDICAL CENTER—LONG BEACH	87	7	5.82	1.20	8.05	1.60	6.69	11.78	
ST. VINCENT MEDICAL CENTER	74	2	2.14	0.93	2.70	0.00	2.89	6.65	
STANFORD UNIVERSITY HOSPITAL	269	10	6.23	1.61	3.72	0.51	2.31	4.12	
SUMMIT MEDICAL CENTER ★	325	5	11.85	0.42	1.54	1.73	3.65	5.57	Better than Expected
SUTTER MEMORIAL HOSPITAL ★	1534	25	42.71	0.59	1.63	1.99	2.78	3.58	Better than Expected
THE HEART HOSPITAL, INC.	133	1	3.58	0.28	0.75	0.00	2.69	5.39	
TORRANCE MEMORIAL MEDICAL CENTER	401	20	16.72	1.20	4.99	2.33	4.17	6.01	
TRI–CITY MEDICAL CENTER	431	7	10.31	0.68	1.62	0.97	2.39	3.82	
UCLA MEDICAL CENTER	191	7	6.10	1.15	3.66	0.81	3.19	5.57	
UC SAN DIEGO UNIVERSITY MEDICAL CENTER (THORNTON AND HILLCREST)	191	9	7.39	1.22	4.71	1.17	3.87	6.57	
UCSF/MT ZION	44	2	1.40	1.43	4.55	0.00	3.18	8.40	
UNIVERSITY OF CALIFORNIA DAVIS MEDICAL CENTER	74	2	1.62	1.23	2.70	0.00	2.19	5.52	

★ Better than expected mortality rate, ▼ Worse than expected mortality rate.

Table F–6: Risk–Adjusted Results for CCMRP Hospitals, 1997–1998, Sorted Alphabetically

Name	Total CABG Cases Submitted	Number of Observed Deaths	Number of Expected Deaths	O/E Ratio	Observed Death Rate (%)	Lower 95% CI of Expected Death Rate (%)	Expected Death Rate (%)	Upper 95% CI of Expected Death Rate (%)	Overall Performance Rating (blank = no different than expected)
UNIVERSITY OF CALIFORNIA IRVINE MED CTR	94	0	3.13	0.00	0.00	0.00	3.33	6.89	
USC UNIVERSITY HOSPITAL	144	4	2.74	1.46	2.78	0.00	1.90	4.15	
WASHINGTON HOSPITAL—FREMONT	334	14	17.07	0.82	4.19	2.92	5.11	7.30	

★ Better than expected mortality rate, ▼ Worse than expected mortality rate.

Table F–7: Risk–Adjusted Results for CCMRP Hospitals, 1997–1998, Sorted by O/E Ratio

Name	Total CABG Cases Submitted	Number of Observed Deaths	Number of Expected Deaths	O/E Ratio	Observed Death Rate (%)	Lower 95% CI of Expected Death Rate (%)	Expected Death Rate (%)	Upper 95% CI of Expected Death Rate (%)	Overall Performance Rating (blank = no different than expected)
LANCASTER COMMUNITY HOSPITAL	23	0	0.76	0.00	0.00	0.00	3.31	9.49	
UNIVERSITY OF CALIFORNIA IRVINE MED CTR	94	0	3.13	0.00	0.00	0.00	3.33	6.89	
ENCINO TARZANA REGIONAL MEDICAL CENTER	145	2	7.17	0.28	1.38	1.36	4.94	8.53	
THE HEART HOSPITAL, INC.	133	1	3.58	0.28	0.75	0.00	2.69	5.39	
SAN ANTONIO COMMUNITY HOSPITAL	124	3	7.56	0.40	2.42	2.25	6.10	9.94	
DOCTORS MEDICAL CENTER—SAN PABLO	169	3	7.28	0.41	1.78	1.42	4.31	7.21	
SUMMIT MEDICAL CENTER ★	325	5	11.85	0.42	1.54	1.73	3.65	5.57	Better than Expected
SHARP GROSSMONT HOSPITAL	133	1	2.34	0.43	0.75	0.00	1.76	4.02	
EL CAMINO HOSPITAL	52	1	2.14	0.47	1.92	0.00	4.11	8.96	
HOAG MEMORIAL HOSPITAL PRESBYTERIAN ★	496	9	17.98	0.50	1.81	2.03	3.63	5.22	Better than Expected
SALINAS VALLEY MEMORIAL HOSPITAL	135	2	3.88	0.52	1.48	0.08	2.87	5.67	
DANIEL FREEMAN MEMORIAL HOSPITAL	173	2	3.86	0.52	1.16	0.01	2.23	4.44	
KAWEAH DELTA DISTRICT HOSPITAL	562	9	16.51	0.55	1.60	1.59	2.94	4.28	
MERCY MEDICAL CENTER–REDDING	114	3	5.49	0.55	2.63	1.05	4.82	8.58	
LONG BEACH MEMORIAL MEDICAL CENTER	378	7	12.01	0.58	1.85	1.42	3.18	4.93	
SUTTER MEMORIAL HOSPITAL ★	1534	25	42.71	0.59	1.63	1.99	2.78	3.58	Better than Expected
TRI–CITY MEDICAL CENTER	431	7	10.31	0.68	1.62	0.97	2.39	3.82	
ST. JOHN'S REGIONAL MED CENTER – OXNARD	90	2	2.91	0.69	2.22	0.00	3.24	6.84	
ST. HELENA HOSPITAL AND HEALTH CENTER	419	8	11.27	0.71	1.91	1.15	2.69	4.23	
GLENDALE MEM HOSPITAL AND HEALTH CENTER	223	8	10.98	0.73	3.59	2.13	4.92	7.72	
ST. JOHN'S HOSPITAL—SANTA MONICA	256	5	6.80	0.74	1.95	0.72	2.66	4.60	
SCRIPPS MEMORIAL HOSPITAL—LA JOLLA	674	15	19.92	0.75	2.23	1.74	2.96	4.17	
DAMERON HOSPITAL	107	3	3.97	0.76	2.80	0.30	3.71	7.11	
SHARP MEMORIAL HOSPITAL	304	4	5.24	0.76	1.32	0.25	1.73	3.20	
ST. BERNARDINE MEDICAL CENTER	405	11	14.40	0.76	2.72	1.76	3.56	5.35	

★ Better than expected mortality rate, ▼ Worse than expected mortality rate.

Table F–7: Risk–Adjusted Results for CCMRP Hospitals, 1997–1998, Sorted by O/E Ratio

Name	Total CABG Cases Submitted	Number of Observed Deaths	Number of Expected Deaths	O/E Ratio	Observed Death Rate (%)	Lower 95% CI of Expected Death Rate (%)	Expected Death Rate (%)	Upper 95% CI of Expected Death Rate (%)	Overall Performance Rating (blank = no different than expected)
PROVIDENCE SAINT JOSEPH MEDICAL CENTER	232	3	3.74	0.80	1.29	0.00	1.61	3.25	
SETON MEDICAL CENTER	1249	18	22.21	0.81	1.44	1.04	1.78	2.52	
WASHINGTON HOSPITAL—FREMONT	334	14	17.07	0.82	4.19	2.92	5.11	7.30	
KAISER FOUNDATION HOSP—SUNSET (L.A.)	2302	31	37.66	0.82	1.35	1.12	1.64	2.15	
MERCY GENERAL HOSPITAL	2565	32	38.37	0.83	1.25	1.03	1.50	1.97	
SEQUOIA HOSPITAL	483	18	21.36	0.84	3.73	2.67	4.42	6.18	
REDDING MEDICAL CENTER	1037	14	16.22	0.86	1.35	0.81	1.56	2.32	
CEDARS–SINAI MEDICAL CENTER	868	19	21.54	0.88	2.19	1.46	2.48	3.50	
ST. FRANCIS MEDICAL CENTER	62	3	3.39	0.89	4.84	0.00	5.46	11.00	
ST. VINCENT MEDICAL CENTER	74	2	2.14	0.93	2.70	0.00	2.89	6.65	
NORTHRIDGE HOSPITAL MEDICAL CENTER	301	9	8.91	1.01	2.99	1.04	2.96	4.88	
LITTLE COMPANY OF MARY HOSPITAL	160	4	3.84	1.04	2.50	0.03	2.40	4.77	
COMMUNITY MEM HOSP—SAN BUENAVENTURA	202	4	3.81	1.05	1.98	0.00	1.89	3.78	
GLENDALE ADVENTIST MEDICAL CENTER	203	7	6.35	1.10	3.45	0.83	3.13	5.43	
PROVIDENCE HOLY CROSS MEDICAL CENTER	114	3	2.70	1.11	2.63	0.00	2.37	5.19	
CITRUS VALLEY MEDICAL CENTER—IC CAMPUS	430	16	14.35	1.12	3.72	1.65	3.34	5.03	
SADDLEBACK MEMORIAL MEDICAL CENTER	175	9	8.03	1.12	5.14	1.52	4.59	7.66	
KAISER FOUNDATION HOSP—GEARY (S.F.)	992	21	18.58	1.13	2.12	1.05	1.87	2.69	
UCLA MEDICAL CENTER	191	7	6.10	1.15	3.66	0.81	3.19	5.57	
MARIN GENERAL HOSPITAL	94	2	1.74	1.15	2.13	0.00	1.85	4.59	
ST. JOSEPH'S MEDICAL CENTER OF STOCKTON	610	20	17.31	1.16	3.28	1.55	2.84	4.13	
PALOMAR MEDICAL CENTER	349	13	11.08	1.17	3.72	1.40	3.18	4.95	
METHODIST HOSPITAL OF SOUTHERN CALIFORNIA	428	17	14.26	1.19	3.97	1.64	3.33	5.02	
TORRANCE MEMORIAL MEDICAL CENTER	401	20	16.72	1.20	4.99	2.33	4.17	6.01	
ST. MARY MEDICAL CENTER—LONG BEACH	87	7	5.82	1.20	8.05	1.60	6.69	11.78	

★ Better than expected mortality rate, ▼ Worse than expected mortality rate.

Table F–7: Risk–Adjusted Results for CCMRP Hospitals, 1997–1998, Sorted by O/E Ratio

Name	Total CABG Cases Submitted	Number of Observed Deaths	Number of Expected Deaths	O/E Ratio	Observed Death Rate (%)	Lower 95% CI of Expected Death Rate (%)	Expected Death Rate (%)	Upper 95% CI of Expected Death Rate (%)	Overall Performance Rating (blank = no different than expected)
SHARP CHULA VISTA MEDICAL CENTER	531	23	18.94	1.21	4.33	2.01	3.57	5.12	
UCSD/SAN DIEGO—UNIVERSITY MEDICAL CTR	191	9	7.39	1.22	4.71	1.17	3.87	6.57	
ST. JOSEPH HOSPITAL—ORANGE	293	8	6.57	1.22	2.73	0.54	2.24	3.94	
UNIVERSITY OF CALIFORNIA DAVIS MED CTR	74	2	1.62	1.23	2.70	0.00	2.19	5.52	
MT DIABLO MEDICAL CENTER	561	20	15.91	1.26	3.57	1.49	2.84	4.18	
DOMINICAN SANTA CRUZ HOSPITAL – SOQUEL	272	10	7.84	1.28	3.68	0.98	2.88	4.79	
ANAHEIM MEMORIAL MEDICAL CENTER	130	4	3.08	1.30	3.08	0.00	2.37	4.89	
SANTA BARBARA COTTAGE HOSPITAL	267	9	6.75	1.33	3.37	0.65	2.53	4.41	
DOCTORS MEDICAL CENTER —MODESTO	451	11	8.22	1.34	2.44	0.57	1.82	3.07	
POMONA VALLEY HOSPITAL MEDICAL CENTER	527	18	13.11	1.37	3.42	1.19	2.49	3.79	
MEMORIAL HOSPITAL MODESTO	550	16	11.55	1.39	2.91	0.89	2.10	3.31	
LOS ANGELES CO USC MEDICAL CENTER	146	4	2.87	1.39	2.74	0.00	1.96	4.20	
UCSF/MT ZION	44	2	1.40	1.43	4.55	0.00	3.18	8.40	
USC UNIVERSITY HOSPITAL	144	4	2.74	1.46	2.78	0.00	1.90	4.15	
ALVARADO HOSPITAL MEDICAL CENTER	298	16	10.71	1.49	5.37	1.51	3.59	5.68	
ALTA BATES MEDICAL CENTER	276	11	7.29	1.51	3.99	0.83	2.64	4.46	
RIVERSIDE COMMUNITY HOSPITAL	86	7	4.57	1.53	8.14	1.00	5.32	9.64	
ST. JUDE MEDICAL CENTER	205	8	5.13	1.56	3.90	0.40	2.50	4.61	
MILLS–PENINSULA MEDICAL CENTER	323	14	8.92	1.57	4.33	1.04	2.76	4.48	
SANTA MONICA—UCLA MEDICAL CENTER	45	2	1.25	1.60	4.44	0.00	2.78	7.64	
STANFORD UNIVERSITY HOSPITAL	269	10	6.23	1.61	3.72	0.51	2.31	4.12	
DESERT REGIONAL MEDICAL CENTER	122	5	2.91	1.72	4.10	0.00	2.39	5.12	
CALIFORNIA PAC MED CTR–PACIFIC CAMPUS	176	6	3.47	1.73	3.41	0.00	1.97	4.03	
MEDICAL CENTER AT THE UCSF	141	7	3.95	1.77	4.96	0.29	2.80	5.30	
GRANADA HILLS COMMUNITY HOSPITAL	142	4	2.13	1.88	2.82	0.00	1.50	3.52	
PRESBYTERIAN INTERCOMMUNITY HOSPITAL ▼	117	9	4.55	1.98	7.69	0.69	3.89	7.08	Worse than Expected
DOWNEY COMMUNITY HOSPITAL ▼	239	13	6.53	1.99	5.44	0.72	2.73	4.75	Worse than Expected
MERCY SAN JUAN HOSPITAL ▼	408	17	7.92	2.15	4.17	0.60	1.94	3.28	Worse than Expected
JOHN MUIR MEDICAL CENTER ▼	128	9	2.97	3.03	7.03	0.00	2.32	4.91	Worse than Expected

★ Better than expected mortality rate, ▼ Worse than expected mortality rate.